Improving Mesoscale Prediction of Shallow Convection and Cloud Regime Transitions in NRL COAMPS

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LONG-TERM GOALS

Accurate predictions of cloud and precipitation processes in the marine boundary layer are critical to U.S. Navy operations, as well as being more broadly important to improving seasonable predictability and the performance of NWP models. The major goal of the project is to develop state of the art boundary-layer parameterizations to be able to represent the continuum from stratocumulus to trade cumulus.

OBJECTIVES

Mesoscale prediction of cloudy boundary layers in mesoscale models is currently hindered the ability of the models to represent shallow cumulus boundary layers and transitions between different cloud regimes.

In order to improve the ability of mesoscale models to correctly represent the continuum of cloudy boundary layers, we have the following objectives:

1. Implement a consistent eddy-diffusivity mass-flux (EDMF) boundary layer parameterization in COAMPS
2. Evaluate the EDMF parameterization using a suite of cases spanning the continuum of boundary layer cloud regimes

APPROACH

Traditional boundary-layer parameterizations incorporated in mesoscale models are based on an eddy-diffusivity (*K*–theory) approach and perform admiribly for dry convective boundary layers and reasonably well for well-mixed, stratocumulus-topped boundary layers. Over a range of grid spacing from ~4–10 km, however, the model exhibits a hysteresis, as surface fluxes of heat and moisture increase boundary layer instability (convective available potential energy; CAPE) more rapidly than

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the subgrid-scale boundary layer scheme can diffuse the instability. Eventually, the amount of instability is sufficient that explicit convection develops on the mesoscale grid, and the magnitudes of updraft, liquid water content, and precipitation associated with these resolved circulations is unrealistically large.

In addition, intermediate boundary layer structures exist between pure stratocumulus and pure trade cumulus. We refer to these intermediate forms as *cloud regime transitions*, either temporal transitions as a stratocumulus cloud system breaks up into a field of trade cumulus, or a spatial transition, as a field of stratocumulus is adjacent to or interspersed with more broken cloud areas (termed "POCs" or pockets of open cells). The overarching goal of the project will be to improve the parameterization of shallow convective processes in NRL COAMPS in order to better represent the trade cumulus regime and regions where cloud regime transitions are associated with shallow convection. This goal will be accomplished via the following specific research objectives.

1. Implementation of a consistent eddy-diffusivity mass-flux (EDMF) scheme in COAMPS

An EDF approach is an elegant way to resolve the dilemma outlined above. The EDMF method partitions the turbulent fluxes into a sum of diffusive and nonlocal contributions. The nonlocal contribution can give rise to countergradient (antidiffusive) transports, in which the turbulent fluxes at any given location are unrelated to the local mean gradient.

As conceived in Siebesma et al. (2007), EDMF "opens the way to parameterize the clear and cumulus-topped boundary layer in a simple and unified way." The studies by the Royal Netherlands Meteorological Institute (KNMI) group that formulated the EDMF approach have concentrated on evaluating the applicability of the EDMF approach for shallow cumulus, and from the transition from shallow cumulus to dry convection (see discussion on Fig. 5 in Neggers et al. 2009). But the attraction of the scheme is that it provides a unified framework for representing the full range of cloudy boundary layers, ranging from pure stratocumulus (eddy diffusivity) to the trade cumulus regime (mass-flux approach, with eddy diffusion parameterizing the subcloud transports), as well as the cloud regime transitions where both diffusion and the mass-flux treatment are appropriate. The strongly drizzling transition regime in particular has characteristics that make it amenable to a mass-flux approach, specifically strong updrafts rooted in the subcloud layer. The unified EDMF framework will represent properly the continuum between stratocumulus-topped boundary layer and trade cumulus. From a parameterization point of view, different locations on the stratocumulus-to-trade-cumulus continuum represent different weightings of the diffusive and nonlocal transports.

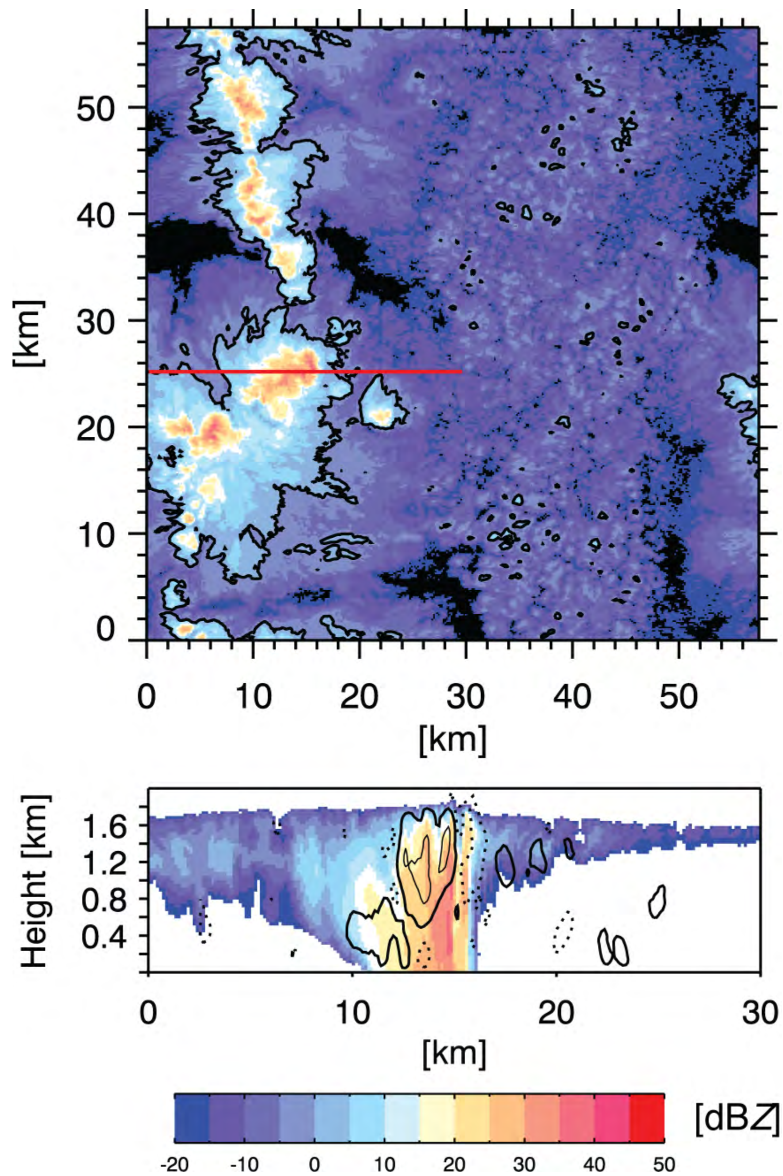

Figure 1. Model reflectivity for an idealized large-eddy simulation of a VOCALS case. (a) Composite reflectivity, with the 0 dBZ contour representing sensitivity of C-band radar. (b) Vertical cross section of reflectivity and vertical velocity through the red line in (a). Contours represent vertical velocity values of ±0.5 and ±2.5 m s^{-1} (from Mechem et al. 2011) [graph: Simulated cloud system exhibits characteristics of both stratocumulus and shallow cumulus. Drizzle cells are deep and contain reflectivity values > 40 dBZ].

2. Comprehensive evaluation of EDMF scheme using a suite of cloudy boundary layer cases

The implementation of EDMF into COAMPS will be evaluated with a suite of simulations based on different boundary layer cloud regimes. We will employ datasets and large-eddy simulation results from BOMEX (Barbados Oceanographic and Meteorological Experiment), RICO (Rain in Cumulus over the Ocean), ATEX, and VOCALS. Datasets from these field projects have been analyzed, and BOMEX, RICO, and ATEX have been the subject of large-eddy simulation intercomparisons (with the PI participating in the most recent RICO GEWEX Cloud Systems Study (GCSS) intercomparison), with output results readily available. The PI is active in the VOCALS community, which is appropriate since VOCALS contains some of the best and most challenging to simulate examples of cloud regime transitions.

To be most useful for Naval applications, the parameterization will be evaluated by looking at “real” cases. Once the EDMF scheme has been successfully tested and tuned in an idealized framework for the BOMEX, RICO, ATEX, and VOCALS cases, we will proceed to evaluating the parameterization using a more realistic mesoscale framework. Extended-length (multi-week) mesoscale simulations corresponding to the RICO and VOCALS campaigns will provide an acid test for how the EDMF parameterization represents a pure trade cumulus regime and a cloud transition regime characterized by heavy drizzle and cumulus rising into a stratocumulus layer.

WORK COMPLETED

The grant began in August 2011, so the project is only in its beginning stages.

The following tasks have been begun:

1. Identifying test cases to evaluate the behavior of operational COAMPS in trade cumulus and cloud transition regimes relative to high-resolution large-eddy simulation results.
2. Planning stategy for implementing eddy-diffusivity mass-flux parameterization into COAMPS.

RESULTS

As previously mentioned, the grant is only in its second month and work has only begun.

One of the test cases will be based on simulations of VOCALS cloud systems currently underway. The case is based on the cloud system observed by the NOAA ship Ronald Brown on 26 October 2008. Large-eddy simulation of the cloud system (Fig. 1) indicates characteristics of both stratocumulus and trade cumulus (Mechem et al. 2011) and constitutes an acid test for a mesoscale model.

IMPACT/APPLICATIONS

More sophisticated boundary layer parameterizations implemented into COAMPS will result in more accurate mesoscale weather prediction for U.S. Navy operations and improved seasonal prediction. Of particular emphasis is accurate forecasts of boundary-layer cloud properties and radiative quantities.

RELATED PROJECTS

This project will rely on our NOAA-funded efforts investigating cloud system variability (employing large-eddy simulation and ship-based C-band precipitation radar) during the VOCALS field campaign. The VOCALS cloud systems constitute a stringent test for mesoscale models. We will also employ our study of marine boundary layer cloud systems over the Azores (DOE grant) to broaden the types of cloud systems employed to test COAMPS.

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